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Constraining the Shock Conditions Experienced by Haughton Crystalline Basement Rocks: A Combined Raman Spectroscopy and Electron Backscatter Diffraction Study of Anomaly Hill Zircons

Haley A. M. Jurak[1], Erin L. Walton[1], Nick E. Timms[2], Gordon R. Osinski[3]

Department of Physical Sciences, MacEwan University[1]; School of Earth and Planetary Sciences, The Institute for Geoscience Research (TIGeR), Curtain University[2]; Department of Earth Sciences / Institute for Earth and Space Exploration, University of Western Ontario[3]

Introduction

Haughton is a 23-km diameter impact structure on Devon Island, Canada [1, 2]. The target stratigraphy comprised ~1880 m of Lower Paleozoic sedimentary rocks, unconformably overlying the Precambrian Canadian Shield [2]. Near the centre of the structure, is a location characterized by negative gravimetric and positive magnetic anomalies, known as “Anomaly Hill” [3]. Highly-shocked, pumice-like lithic clasts are abundant at this locale, and include gneissic and carbonate-rich clasts [4, 5]. In this study, we examined 20 zircon grains from a single crystalline clast collected at Anomaly Hill, to reveal microstructures at the micrometer to nanometer scale. Earlier work on Haughton zircons [6] did not incorporate EBSD, and so, is missing a wealth of information to facilitate the identification of key microstructures including FRIGN (former reidite in granular neoblasts) zircon, non-FRIGN granular textures, neoblasts versus sub-grain rotation formation of subdomains, and various dissociation textures, as described in [7, 8]. The goal of our study is to constrain the shock conditions experienced by crystalline basement rocks at Haughton using zircon, a mineral that is increasingly recognized as a sensitive shock indicator.

Samples and Methods

Twenty Zr-bearing grains were characterized using a petrographic microscope, a ZEISS Sigma 300 FESEM in BSE imaging mode and a micro-Raman spectrometer. A 532 nm Ar+ laser was directed through the 100X objective lens of an optical microscope to achieve a ~1 µm spot size. Peak positions and intensities in the Raman spectrum were compared to those acquired from zircon, baddeleyite, and reidite reported by [9]. Phase and orientation maps of 18 zircon grains were acquired via EBSD mapping with a Tescan MIRA3 FESEM fitted with Oxford Instruments Aztec combined EDS-EBSD system. EBSD/EDS data were collected using an EBSD detector and XMax 20 mm SDD EDS detector with a specimen tilt of 70°, acceleration voltage of 20 kV, and a working distance of 18.5 mmEBSD data were processed using Oxford Instruments Channel 5.12 by removing isolated erroneous data points via a ‘wildspike’ filter, followed by extrapolative infill of unindexed points using a minimum of seven nearest neighbours. Maps of EBSD pattern quality, phase, crystallographic orientation, and pole figures were produced in Channel 5.12.

Results and Discussion

Shock Effects in Zircon: Zircon records a range of distinct microstructures, including: crystalline zircon with no definitive evidence of shock, but some fracturing and limited crystal-plasticity (n = 10); poor crystallinity zircon, often with irregular fractures and microvesicles (n = 3); lamellar reidite within zircon (n = 2); patchy and/or granular textured reidite (n = 3); and granular textured zircon (n = 2). No evidence of planar deformation bands, shock twins, or thermal decomposition, were observed.

Lamellar reidite appear in BSE images as thin (<1 µm wide), closely-spaced sets of bright, roughly parallel lamellae that cut across the primary growth zoning of zircon. These lamellae are identified as reidite by a broad, low-intensity peak at 608 cm^{-1} in the Raman spectrum, along with a doublet at 816 and 862 cm^{-1}. Peaks are accompanied by a triplet at 192, 200, and 212 cm^{-1}, and sharp, well-defined peaks at 344, 426, 962, and 994 cm^{-1}, all of which are consistent with zircon. Reidite lamellae yield poor EBSD patterns that could not be indexed. Granular reidite occurs as sub-micrometer size individual grains in poorly crystalline zircon and is spatially associated with fractures and grain margins of highly-crystalline zircon. In contrast to lamellar reidite, reidite with this texture are indexed well by EBSD mapping. EBSD maps show that reidite typically has a distinctive epitaxial crystallographic orientation relationship with the host zircon, with one $\{110\}_{\text{reidite}}$ aligned with $(001)_{\text{zircon}}$, and the other $\{110\}_{\text{reidite}}$ aligned with $\{110\}_{\text{zircon}}$. These relationships have been described elsewhere [7, 10] and are readily explained by transformation from a single zircon orientation via multiple symmetrically equivalent pathways, resulting in broadly two orthogonal reidite orientations. Discrete, sub-micrometer granular-textured zircon domains are spatially associated with reidite, and predominantly define up to three mutually orthogonal crystallographic orientation clusters. This microstructure is attributed to neoblasts formed by back-transformation to zircon from reidite [7], a texture termed FRIGN by [8].

The remaining zircons described in this study exhibit typical igneous textures, with a subset possessing highly porous growth zones and margins. These porous grains yield Raman spectra that exhibit low intensity, broad peaks at 344, 426, 962, and 994 cm^{-1}. Broadened peaks in the Raman spectrum suggest these materials are poorly crystalline, consistent with localized radiation damage of U-rich growth zones (i.e., metamict zircon). Vesicles are interpreted as a consequence of degassing from pre-existing impurity-rich metamict domains during impact-related heating.

Conclusions

Our combined FESEM, Raman and EBSD study has identified reidite exhibiting a range of microtextures in a subset of zircon grains. The presence of FRIGN zircon, identified for the first time at Haughton (this study), but lack of zircon dissociation textures, indicates that basement temperatures locally reached >1200°C but did not exceed ~1673°C. Based on the experimentally-determined stability of reidite [e.g., 13], shock pressures were >30 GPa, consistent with a shock stage III classification [11]. However, the heterogeneous distribution of shock features in zircon suggests that shock pressure and temperature conditions varied locally at the grain scale.

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